# Two for One: Simultaneous X-ray Measurements of Dissolved Gas and Cavitation Bubbles

Understanding the dynamics of dissolved gases in fluids is essential to many scientific and engineering endeavors. Where large pressure changes exist, cavitation can also occur. Both phenomena cause bubbles to form in fluids, but the two are difficult to distinguish from one another when scientifically measured. This is particularly important when trying to understand the extent that a dissolved gas diffuses into cavitation bubbles in turbulent flows such as those found in high-pressure nozzles. In this study, researchers applied x-ray fluorescence (XRF) to determine both the density of a liquid flow and the concentration of noncondensible gas. Their experiment was performed at the APS with a submerged cylindrical nozzle under cavitating conditions. With complimentary results obtained earlier from other diagnostic techniques, their results further the understanding of gas diffusion into cavitation bubbles. Information gleaned from this study will improve methods of design and manufacture to reduce cavitation erosion, which causes extensive damage to machinery such as control valves, propellers, and pumps.

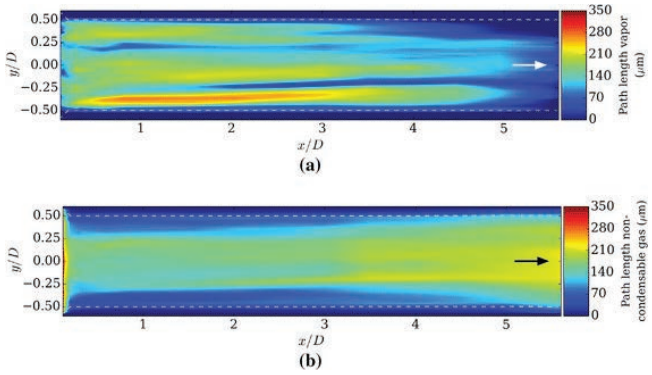


Fig. 1. Time-average maps of line of sight equivalent path length of (a) total displaced liquid from Br fluorescence and (b) Kr from fluorescence (expanded at $P_2$ under ideal gas conditions)taken at the XSD 7-BM beamline at the APS. The arrows indicate the direction of the freestream flow.

At the center of their experiment is the study of the dynamics of dissolved gas (any gas that dissolves into another solute) and cavitation (the formation of vapor cavities in a fluid when subjected to tension, typically due to low pressure). The experimenters used a cylindrical test nozzle, with dimensions of 0.5-mm diameter and 3.05-mm length, manufactured from a thermoplastic polymer called polyether ether ketone (PEEK). The exit portion of the nozzle was submerged in liquid during the experiment, while maintained at a constant pressure.

The fluid used in the experiment, a gasoline surrogate, was doped with 400 ppm of a bromine (Br) additive called tetrabromomethane (CBr4; also known as carbon tetrabromide). The dissolved air in the fluid was removed by degassing and replaced with krypton (Kr) gas. The procedure involved evacuating a storage tank, moving the contents into a piston accumulator, and pumping it through a brass orifice to assure the removal of excess air. The degassed fluid was then vacuum-stored for several hours. Krypton gas was bubbled through the fluid until an equilibrium pressure was reached.

Conducting the experiment at the XSD 7-BM-B beamline, the researchers from Argonne focused a 15-keV monochromatic x-ray beam using Kirkpatrick-Baez mirror optics. The beam simultaneously excited fluorescent emission from the Br and Kr components within the fluid. The emission from the K edges of Br and Kr were recorded using a silicon drift diode detector. The incoming beam intensity was normalized using a diamond transmission photodiode. Total displacement of the liquid was measured from Br fluorescence, while the mass fraction of both the dissolved and nucleated gas was measured from Kr fluorescence (Fig. 1).

The team corrected for systematic errors in measurements due to reabsorption, intensity calibration, and detector dead-time. Various experimental uncertainties were also taken into account. Specifically, the researchers found uncertainties of 2.4% and 3.6% associated with projected densities of the liquid (Br) and gas (Kr) phases before reabsorption correction, and 4.3% and 6.4% after iterative reabsorption correction, respectively. The Kr/Br mass ratio was measured with an uncertainty of 8.3%. These analytic measurements were validated with independent diagnostic techniques, such as x-ray radiography.

Based on their experiments, the researchers concluded that many of the voids found exiting the nozzle are due not only to cavitation vapor. Instead, they discovered that these voids were also partially filled with nucleated gas. Ultimately, the expansion of dissolved gas into the voids formed by cavitation act to stabilize the bubbles and prevent them collapsing.

The information collected from this experiment will help in the many fields relevant to the fluid-flow dynamics of dissolved gas and cavitation. For instance, hydraulic oil can be adversely affected by the precipitation of gas bubbles, as can the presence of gas bubbles within nozzles used in high-pressure, direct fuel-injection systems found within internal combustion engines. In such cases, quantitative measurements, like the ones produced in this study with XRF, can help to minimize such serious problems.

*— William Arthur Atkins*

*See:* Daniel J. Duke*‡, Alan L. Kastengren, Andrew B. Swantek, >>

<< Katarzyna E. Matusik, and Christopher F. Powell, "X-ray fluorescence measurements of dissolved gas and cavitation," Exp. Fluids **57**, 162 (2016). DOI 10.1007/s00348-016-2250-5
*Author affiliation:* Argonne National Laboratory ‡Present address: Monash U.
*Correspondence:*
* daniel.duke@monash.edu

Argonne's fuel injection research is sponsored by the U.S. Department of Energy (DOE) Vehicle Technologies Program under the direction of Gurpreet Singh and Leo Breton. This research used resources of the Advanced Photon Source, a U.S. DOE Office of Science User Facility operated for the DOE Office of Science by Argonne National Laboratory under Contract No. DE-AC02-06CH11357.

*"Ionic" cont'd. from page 76*

APS suggest the RTIL's layered structure has two stable states—one when the electrode's potential is positive, the other when the electrode potential is negative. The results suggest that these two stable states are separated by an energy barrier, which has a size of approximately 0.15 eV. This energy barrier is sufficiently large that it takes time (and energy) for the ions to cross over it, leading to the observed hysteresis. The team also noted intermediate states — mixed patches of anion and cations— while the potential applied to the graphene surface changed. The team members from Vanderbilt created a computer model that successfully reproduced those intermediate states, confirming that the researchers understood mathematically what is going on.

The next step will be to figure out what is happening in various RTILs. Specifically, the researchers want to know how the physical structure of the molecules in the RTIL contributes to the hysteresis. If the researchers can understand that, they can design RTILs with molecular properties that cause as little hysteresis as possible.

*— Kim Krieger*

*See:* Ahmet Uysal[1]*, Hua Zhou[1], Guang Feng[2]**, Sang Soo Lee[1], Song Li[2], Peter T. Cummings[2], Pasquale F. Fulvio[3]‡, Sheng Dai[3], John K. McDonough[4], Yury Gogotsi[4], and Paul Fenter[1]***, "Interfacial ionic 'liquids': connecting static and dynamic structures," J. Phys. Condens. Matter **27** 032101 (2015).
DOI: 10.1088/0953-8984/27/3/032101
*Author affiliations:* [1]Argonne National Laboratory, [2]Vanderbilt University, [3]Oak Ridge National Laboratory, [4]Drexel University ‡Present address: University of Puerto Rico
*Correspondence:* * ahmet@anl.gov
** gfeng@hust.edu.cn
*** pfenter@anl.gov

This work was supported as part of the Fluid Interface Reactions, Structures and Transport Center, an Energy Frontier Research Center funded by the U.S. Department of Energy (DOE) Office of Science-Basic Energy Sciences. This research used resources of the Advanced Photon Source, a U.S. DOE Office of Science User Facility operated for the U.S. DOE Office of Science by Argonne National Laboratory under Contract No. DE-AC02-06CH11357.

*"Monolayers" cont'd. from page 77*

The researchers from the University of Leeds (UK), SLAC National Accelerator Laboratory, DESY (Germany), University College London (UK), and Argonne also observed a most unexpected result. Each crystal contained a single dislocation loop that occupied exactly the same position within all of the sample crystals. The loop forms to relieve the stress field present at the crystal/substrate interface, where this strain increases as the crystal's volume increases. When stored elastic energy exceeds the energy needed to make a dislocation loop, then a dislocation grows to relieve the stress.

This dislocation loop has a different geometry from the "misfit dislocations" frequently observed in epitaxial inorganic heterostructures. In "classic" misfit dislocations, the apex of the loop is located at the interfaces between the substrate and overlayer. It has edge character parallel to the interface, which reduces the strain that occurs in the crystal overlayer because of the differences in lattice structure between the substrate and overgrowth crystal.

The dislocation loop formed in the studied organic/inorganic heterostructure system must therefore form by a different mechanism. The team contends that the loop arises from two effects: internal stress due to interfacial defects and the nanoscale roughness of the substrate, where the nanoscale roughness of the substrate is the dominant factor.

This research provides new information about the factors that govern crystallization on organic substrates. It contributes important knowledge about stress relaxation and dislocation formation during epitaxial crystal growth, and demonstrates that the roughness of the substrate—whether organic or inorganic—should be considered when controlling defects and interfacial strain during epitaxial crystal growth.

*— William Arthur Atkins*

*See:* Johannes Ihli[1‡*], Jesse N. Clark[2,3], Alexander S. Côté[4‡‡], Yi-Yeoun Kim[1], Anna S. Schenk[1], Alexander N. Kulak[1], Timothy P. Comyn[1], Oliver Chammas[1], Ross J. Harder[5], Dorothy M. Duffy[4], Ian K. Robinson[4**], and Fiona C. Meldrum[1***], "Strain-relief by single dislocation loops in calcite crystals grown on self-assembled monolayers," Nat. Commun. **7**, 11878 (15 June 2016). DOI: 10.1038/ncomms11878
*Author affiliations:* [1]University of Leeds, [2]SLAC National Accelerator Laboratory, [3]Deutsches Elektronensynchrotron (DESY), [4]University College London, [5]Argonne National Laboratory Present addresses: ‡Paul Scherrer Institute, ‡‡University College London
*Correspondence:*
* johannes.ihli@psi.ch
** i.robinson@ucl.ac.uk
*** F.Meldrum@leeds.ac.uk

This work was supported by FP7-advanced grant from the European Research Council (J.N.C. and I.K.R.), by an Engineering and Physical Sciences Research Council Leadership Fellowship (F.C.M., J.I. and Y.Y.K.; EP/H005374/1) and EPSRC grant EP/K006304/1 (A.N.K.). F.C.M., A.S.S., D.M.D. and A.S.C. are also supported by an EPSRC Programme Grant (grant EP/I001514/1) that funds the Materials Interface with Biology (MIB) consortium. Beamline 34-ID-C was built with funds from the U.S. National Science Foundation under Grant DMR-9724294. This research used resources of the Advanced Light Source, a U.S. Department of Energy (DOE) Office of Science User Facility, under contract no. DE-AC02-05CH11231, and the Advanced Photon Source, a U.S. DOE Office of Science User Facility operated for the U.S. DOE Office of Science by Argonne under Contract No. DE-AC02-06CH11357.